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Development of an E-Module Oriented to Education for Sustainable Development (ESD) to Foster Students' Scientific Literacy

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ABSTRACT

This study developed an Education for Sustainable Development (ESD)-oriented e-module centered on alternative energy sources derived from palm oil waste, aiming to foster students' scientific literacy. A Type I Design and Development Research (DDR) methodology was employed, focusing on product development through the stages of analysis, design, development, and evaluation. The research involved seven chemistry teachers for needs analysis, nine senior high school students from Bandung for a limited trial, and three expert validators According to the validator's assessment, the e-module integrates scientific literacy and Education for Sustainable Development (ESD), and incorporates essential components including an introduction, content exposition, summary, exercises, evaluation, self-reflection, and supplementary materials. Validation results confirm that the e-module meets feasibility criteria, although further improvements to foster scientific literacy were recommended. The final version demonstrates sufficient integration of competencies and scientific literacy elements. Analysis of students' scientific literacy profiles during the limited trial suggests that the e-module has considerable potential to enhance students' scientific literacy. However, additional refinement is required, particularly in item construction and the development of supporting materials.

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INTRODUCTION

Contemporary science education emphasizes student-centered learning processes, with an expectation that students will develop independent learning skills and apply their knowledge, particularly in scientific literacy (Pradini et al., 2022). Scientific literacy refers to an understanding of scientific concepts and processes that enables individuals to make informed decisions, participate in civic, cultural, and economic activities, and demonstrate specific competencies (Fitria & Indra, 2020). Despite these priorities, the Programme for International Student Assessment (PISA) indicates that Indonesian students' scientific literacy remains low and consistently ranks near the bottom internationally (Rohmaya, 2022). This persistent underperformance is attributed to the predominant reliance on textbooks as learning resources in Indonesia, which limits the internalization and practical application of scientific literacy among students (Fuadi et al., 2020). E-modules represent a promising alternative, as they are self-contained, comprehensive, adaptive, and user-friendly (Delita et al., 2022; Romadhon et al., 2024; Sholeha, 2026). E-modules can enhance students' scientific literacy by illustrating phenomena and supporting the development of problem-solving skills (Aribowo et al., 2025; Silaban et al., 2022; Tartiyoso, 2025).

The 2022 independent curriculum guidelines advocate for learning processes oriented toward a sustainable future, aligning with the principles of Education for Sustainable Development (ESD). Integrating ESD into science education is essential for cultivating environmental awareness and preparing students to address sustainability challenges (Kemendikbud Ristek, 2022). ESD-oriented instruction encompasses the three pillars of sustainability: socio-cultural, economic, and environmental dimensions (Tristananda, 2018). The Education for Environmental Sustainable Development (EESD) approach can be effectively implemented in science education to equip students with environmental knowledge and improve scientific literacy (Ekantini & Wilujeng, 2018).

The adoption of Education for Sustainable Development (ESD)-oriented learning facilitates the identification of diverse environmental challenges by students. Among these, waste generation—particularly solid palm oil waste—represents a significant concern. Data from the Indonesian Palm Oil Plantation Fund Management Agency (BPDPKS) indicate that the palm oil industry generates approximately 60 million tons of waste annually, encompassing both liquid and solid forms. Inadequate management of palm oil waste can lead to soil and water contamination, thereby threatening public health and ecosystem stability (Alfiani et al., 2024). Processing solid palm oil waste through pyrolysis offers a potential solution, producing bio-oil, biochar, and gas.

Pyrolysis is the thermal decomposition of biomass at high temperatures without the presence of oxygen. A principal product of biomass pyrolysis is bio-oil, which functions as an alternative energy source. Bio-oil may be used directly as boiler fuel, in the production of fuel oil, and for synthesizing various chemical products (Pitoyo et al., 2022).

The objective of this research is to develop an Education for Sustainable Development (ESD)-oriented e-module focused on alternative energy sources derived from palm oil waste. The e-module validated by experts to ensure its effectiveness in fostering scientific literacy. Additionally, this study seeks to assess the scientific literacy profiles of students utilizing the e-module, thereby identifying its potential to enhance students' scientific literacy.

METHOD

The research method used was Design and Development Research (DDR) type one, which focuses on product development through specific project phases, including analysis, design, development, and evaluation (Richey & Klein, 2007). The Research method can be seen in Figure 1.

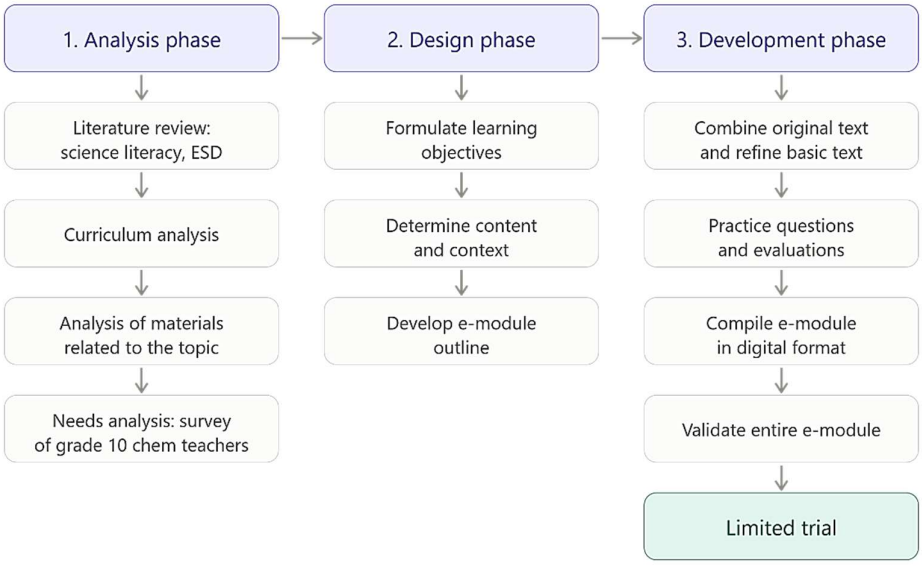


Figure 1. The Research Method Diagram

The analysis phase began with a literature review on science literacy and ESD, curriculum analysis, analysis of materials related to the topic being developed, and an analysis of the e-module development needs based on the results of a preliminary survey of several 10th-grade chemistry teachers. The design phase included the formulation of learning objectives, content and context, and the

development of an e-module outline. These designs were then further developed in the development phase by combining the original text and refining the basic text, formulating practice questions and evaluations, compiling the e-module in digital format, and validating the entire e-module, which then proceeded to a limited trial.

This research involved seven chemistry teachers in the needs analysis phase, three validators (two expert lecturers and one chemistry teacher), and nine 10th-grade students at a high school in Bandung City. Student selection was based on varying levels of academic ability in chemistry, including high, medium, and low categories, each represented by three students. The chemistry teachers involved in the needs analysis phase were selected based on the criteria for teaching chemistry in Phase E. The teachers acting as validators were selected based on the criteria of having more than five years of teaching experience.

The research instruments used were an e-module construction format containing a format for formulating learning objectives, a format for formulating content/context, a format for combining original texts and creating basic texts, as well as a format for formulating practice questions and evaluations; a validation sheet; and a format for analyzing student responses. During the validation and analysis phase of student responses, a triangulation process was conducted between researchers (investigator triangulation) involving three validators and three researchers. This was done to ensure the accuracy of the material and the accuracy of the analysis results based on predetermined indicators and to minimize bias in data analysis and interpretation, thereby increasing the reliability and validity of the research findings (Donkoh, 2023).

RESULT AND DISCUSSION

1. E-Module Design

The development of the e-module design followed several stages: needs analysis, e-module design, and e-module product development. This process resulted in a comprehensive e-module suitable for student use. The needs analysis stage included a literature review on scientific literacy and Education for Sustainable Development (ESD), curriculum analysis, examination of materials relevant to the topic, and an assessment of e-module development needs based on a preliminary survey of seven 10th-grade chemistry teachers. All surveyed teachers agreed that the topic of processing palm oil waste into an alternative energy source could enhance students' scientific literacy. Additionally, six teachers indicated that developing this e-module was necessary to support ESD-oriented learning.

The subsequent stage involved designing the e-module, which encompassed formulating learning objectives, defining content and context, and developing an e-module outline. The learning objectives were aligned with the independent curriculum, specifically targeting science learning outcomes for phase E. The formulation process considered the PISA 2025 scientific literacy components, including scientific competencies, knowledge domains, and scientific identity (OECD, 2023), as well as ESD dimensions such as environmental, social, and economic aspects (Tristananda, 2018). An example of the learning objectives formulation is presented in Table 1.

Table 1 Example of Formulating Learning Objectives

Elements of Understanding	PISA 2025 Knowledge Aspects	PISA 2025 Competency Aspects	ESD aspects	Learning objectives
Alternative energy and its use to overcome energy availability problems	**Content Knowledge** Has relevance to real-life situations	**Explaining Phenomena Scientifically** Explain the potential implications of scientific knowledge for society	**Environment** In relation to efforts to increase public awareness of the impact of human activities on the environment **Socio-cultural** Increasing understanding of health	Directing students to be able to explain phenomena related to the energy crisis and the impact of the use of fossil energy sources on the environment and health through reading texts, videos and graphics (P)

The content and context were formulated based on the previously formulated learning objectives. These objectives were divided into three submodules, each containing content and context related to the topic of processing palm oil waste into alternative energy sources. Examples of content and context formulation are shown in Table 2. Next, an e-module outline was developed, referring to the practical guidelines for developing e-modules according to the Ministry of Education and Culture (Kemendikbud, 2017). In developing an e-module, a simple structure or framework should be chosen that best suits the needs and conditions.

Table 2 Example of Content/Context Formulation

Learning Outcomes	Learning objectives	Content/Context
Knowledge Elements Alternative energy and its use to overcome energy availability problems.	**Sub Module 1: Energy Crisis and Indonesia's Biomass Energy Potential**	
	Directing students to be able to explain phenomena related to the energy crisis and the impact of the use of fossil energy sources on the environment through reading texts, videos and graphics (P)	• Data on the energy crisis, especially oil in Indonesia • The impact of using fossil energy sources

The development stage of the e-module product involves integrating original texts and creating foundational materials, formulating practice questions and assessments, compiling the e-module in digital format, and conducting validation. Original texts are derived from both content-specific and contextual sources that align with the learning objectives. These texts are typically sourced from journal articles and textbooks relevant to the subject matter. Table 3 presents examples of the combined original texts.

Table 3 Example of Original Text Merging

Original Text Context	Original Text of Content	Original Text Combination
Pollution Due to Fossil Fuel Use The industrial revolution of the 18th century initiated the massive use of fossil fuels which caused a drastic increase in carbon emissions (Kemendikbud, 2017)(Omenu & Adinugroho, 2024) .	**Pollution Due to Fossil Fuel Use** Carbon emissions are the result of the combustion of fossil fuels and the cement production process, which includes the release of carbon dioxide that occurs when consuming solid, liquid, and gaseous fuels, as well as during gas combustion. Carbon emissions come from the release of carbon compounds such as carbon dioxide (CO_2) and methane (CH_4) into the atmosphere. These carbon compounds trap heat in the atmosphere when released, thus causing global warming.	**Pollution Due to Fossil Fuel Use** The industrial revolution of the 18th century initiated the massive use of fossil fuels which led to a drastic increase in carbon emissions. Carbon emissions are the result of the combustion of fossil fuels and the cement production process, which includes the release of carbon dioxide that occurs when consuming solid, liquid, and gaseous fuels, as well as during gas combustion. Carbon emissions come from the release of carbon compounds such as carbon dioxide (CO_2) and methane (CH_4) into the atmosphere. These carbon compounds trap heat in the atmosphere when released, thus causing global warming.

The Ministry of Education and Culture (Kemendikbud, 2017) emphasizes that e-modules should be written and designed specifically for student use. To enhance student comprehension, the text within the e-module must be adapted through simplification and refinement, which may include adding or removing specific words and incorporating explanations using images, animations, or videos. These modifications ensure that the basic text is both suitable and engaging for the e-module. Furthermore, the basic text incorporates guiding questions to encourage critical thinking and prepare students for studying the sub-material. Table 4 presents an example of the resulting basic text.

Table 4 Example of Basic Text Creation

Original Text Smoothing	Basic Text
Pollution Due to Fossil Fuel Use The industrial revolution of the 18th century initiated the massive use of fossil	Does the continued use of fossil fuels impact the environment and health? Read the following text to find out!

Original Text Smoothing	Basic Text
fuels which led to a drastic increase in carbon emissions. Carbon emissions ~~are the result~~ comes from the burning of fossil fuels ~~and the cement production process~~ which ~~includes~~ produces oxide compounds such as carbon dioxide (CO_2) ~~release carbon dioxide that occurs when consume uses solid, liquid and gas fuels as well as during gas combustion. Carbon emissions come from the release of carbon compounds such as~~ carbon dioxide (CO_2) ~~and methane (CH_4) into the atmosphere~~, these ~~carbon compounds~~ trap heat when released into ~~the~~ atmosphere ~~when released~~, resulting in global warming and impacting climate change.	**Pollution Due to Fossil Fuel Use**  Figure 1.1 1Pollution Due to Industrial Activities Source: gesi.co.id  Figure 1.2 2Pollution Due to Motor Vehicles Source: www.bbc.com The Industrial Revolution of the 18th century ushered in the massive use of fossil fuels, leading to a drastic increase in carbon emissions. Carbon emissions stem from the combustion of fossil fuels, which produce oxide compounds such as carbon dioxide (CO_2). This carbon dioxide traps heat when released into the atmosphere, contributing to global warming and climate change.

Practice and evaluation questions constitute a key component of the e-module framework, designed to assess students' comprehension of the e-module content (Kemendikbud, 2017). The development of these questions aligns with specified learning objectives and incorporates relevant competencies as well as aspects of scientific literacy. Table 5 provides examples of question formulations included in the e-module.

Table 5 Example of Formulating Practice Questions and Evaluations

Learning objectives	Aspects of Scientific Literacy	Question	Answers Rubric
Directing students to be able to identify alternative energy sources that can be used as a solution to the limitations of fossil energy through information data in the reading text and the available website links (P)	**Knowledge: (Procedural Knowledge)** A common way to abstract and represent data is using tables. **Competence: Explaining Phenomena Scientifically** Identifying, building, and evaluating models	After reading about alternative energy sources that can be used as solutions to the limitations of fossil fuels, identify alternative energy sources and their uses. Then, write your findings in a three-column table containing the number, the alternative energy source, and its uses. (Minimum of 7 alternative energy sources)	Students create a table containing alternative energy sources and their uses. Example table: No. | Sumber Energi Alternatif | Pemanfaatannya 1. | Matahari | Pembangkit listrik, pemanas air tenaga surya 2. | Air | Pembangkit listrik 3. | Angin | Pembangkit listrik 4. | Panas bumi | Pembangkit listrik 5. | Biomassa | Bahan bakar, Pembangkit listrik 6. | Pasang surut air laut | Pembangkit listrik 7. | Hidrogen | Bahan bakar

After obtaining the e-module outline, learning materials, and relevant questions, the subsequent step involves compiling these components into a digital format. According to the Ministry of Education and Culture (Kemendikbud, 2017), three primary considerations guide the selection of an e-module format: device availability, the display size of the reading tool application, and the use of a widely supported format. Based on these criteria, the website format provided by the Canva application was selected. This format is accessible on mobile phones, tablets, laptops, and computers; the display size is adjustable; and it is not restricted to a specific device, enabling broad usability. The structure of the e-

module follows the guidelines established by the Ministry of Education and Culture (Kemendikbud, 2017), which include a cover, foreword, table of contents, concept map, introduction, module usage instructions, learning activities, evaluation, glossary, and bibliography. Screenshots of the e-module display are shown in Figures 2 and 3.



Figure 2. Front Cover View of E-Module

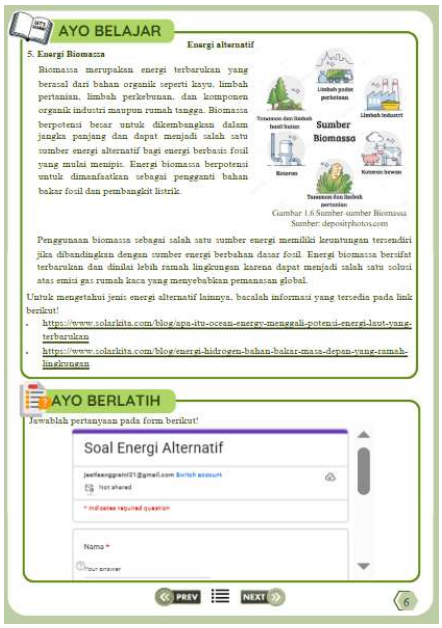


Figure 3. Display of Material Description and Questions

Expert Validation Results

The e-module was evaluated by three experts in chemistry and scientific literacy. The validators assessed the module using four criteria: alignment of the material with learning objectives, relevance of content and context, appropriateness of illustrations, images, and symbols in relation to the text, and suitability of language for student development. The validation results demonstrate that the e-module aligns with Education for Sustainable Development (ESD), particularly in addressing the processing of palm oil waste into an alternative energy source. The validators provided specific notes and suggestions for improvement in certain sections. Examples of text revisions are presented in Table 6.

Table 6 Examples of Text Improvements in E-Modules

Text Before Revision	Text After Revision
The industrial revolution of the 18th century initiated the massive use of fossil fuels, leading to a drastic increase in carbon emissions. Burning fossil fuels produces oxide compounds such as carbon dioxide (CO_2) . Carbon emissions result from the release of carbon compounds, such as carbon dioxide (CO_2) , into the atmosphere. These carbon compounds absorb heat from the atmosphere when released, resulting in global warming and impacting climate change.	The Industrial Revolution of the 18th century ushered in the massive use of fossil fuels, leading to a drastic increase in carbon emissions . Carbon emissions stem from the combustion of fossil fuels, which produce oxide compounds such as carbon dioxide (CO_2) . This carbon dioxide traps heat when released into the atmosphere, contributing to global warming and climate change.

Description: The sentences in blue are part of the correction.

Validation was also carried out on the practice questions and evaluation questions contained in the e-module, with 3 assessment criteria, namely: (1) the suitability of the questions to the learning objectives, (2) the suitability of the questions to the aspects of scientific literacy, and (3) the accuracy of the answer rubric. Based on the validation results, the three validators also stated that the practice questions in the e-module were suitable for use, with revisions to several questions. Examples of improvements to questions in the e-module are presented in Table 7.

Table 7 Examples of Question Improvements in the E-Module

Practice Questions Before Revision	Practice Questions After Improvement
In sub-module 1, you learned that biomass waste such as palm oil waste has negative impacts on the environment and health. As the nation's next generation, would you like to get involved in reducing the issue of palm oil waste by learning how to convert it into fuel using the biomass pyrolysis method? Tell us your reasons!	In sub-module 1, you learned that biomass waste, such as palm oil waste, has negative impacts on the environment and health. To mitigate these issues related to palm oil waste, several researchers are working to utilize palm oil waste as a raw material to produce more useful products. One method that can be used to process palm oil waste is pyrolysis, which produces alternative fuels. a. Do you also want to get involved in reducing issues related to palm oil waste? b. In your opinion, what effective steps will you take to reduce palm oil waste? c. If a seminar and training were held on processing palm oil waste using the pyrolysis method, would you like to be involved in this activity?

Student Scientific Literacy Profiles

The scientific literacy profiles of students were identified through a limited trial involving nine participants representing high, medium, and low ability groups. These profiles were evaluated using responses to practice questions included in the developed e-module. The analysis assessed the suitability and relevance of student answers according to a previously designed and validated answer rubric.

According to the PISA 2025 science framework, competencies developed through science education require three forms of knowledge: content, procedural, and epistemic, as well as aspects of science identity (OECD, 2023). Scientific literacy serves as a means for students to attain these scientific competencies. The combination of science competencies and various aspects of scientific literacy can lead to differing levels of achievement in students' scientific literacy profiles. This variation is reflected in the diverse results of student literacy profiles based on responses to the e-module practice questions. The conclusions regarding the scientific literacy profiles of all students across the 18 practice questions are presented in Table 8.

Table 8 Conclusion of the Results of the Students' Science Literacy Profile

Question No.	Aspects of Scientific Literacy		Tall		Currently			Low			●	◐	○
			PD1	PD2	PD3	PD4	PD5	PD6	PD7	PD8	PD9			
1.	PK1	KS1	●	●	●	●	●	●	●	●	●	9	0	0
2.	PK1	KS1	●	◐	●	◐	●	●	●	◐	●	6	3	0
3.	PP1	KS2	●	●	●	●	●	●	●	●	●	9	0	0
4.	PE1	KS4	●	●	○	●	●	●	◐	◐	●	6	2	1
5.	IS1	KS1	●	●	●	●	●	●	●	●	●	9	0	0
6.	IS1	KS1	●	●	●	●	●	●	●	●	●	9	0	0
7.	PE1	KS2	●	●	●	●	●	●	●	●	●	9	0	0
8.	PK2	KS1	●	◐	◐	●	●	●	◐	●	●	6	3	0
9.	IS2	KS1	◐	◐	◐	●	●	●	●	●	●	6	3	0
10.	PK2	KS1	◐	○	○	●	○	●	●	◐	●	4	2	3
11.	PK2	KS1	●	◐	●	●	●	●	●	◐	●	7	2	0
12.	PK2	KS1	◐	◐	●	●	●	●	◐	◐	●	5	4	0
13.	PP2	KS3	●	●	◐	●	●	○	●	◐	●	6	2	1
14.	IS3	KS3	●	◐	●	●	●	●	●	●	●	8	1	0
15.	PK1	KS5	●	◐	●	●	●	●	●	●	●	8	1	0
16.	PK2	KS5	◐	◐	◐	○	●	●	◐	◐	◐	2	6	1
17.	PK2	KS2	●	◐	◐	●	●	●	●	●	●	7	2	0
18.	PK2	KS1	●	●	○	●	●	●	○	●	●	7	0	2
	●		14	8	10	16	17	17	13	11	17			
	◐		4	9	5	1	0	0	4	7	1			
	○		0	1	3	1	1	1	1	0	0			

Description: ● (achieved), ◐ (partially achieved), and ○ (not yet achieved)
PK: Content Knowledge
- PK 1: Has relevance to real life situations
- PK 2: Representing important scientific concepts

PP: Procedural Knowledge
- PP 1: Common ways of abstracting and representing data using tables
- PP 2: Design suitable for investigation of a scientific question, e.g. experimental

PE: Epistemic Knowledge
- PE 1: The nature of scientific observation, facts, hypotheses, models and theories

IS: Science Identity
- IS 1: Environmental awareness, concern and agency (Awareness of environmental issues)
- IS 2: Affective elements in science identity (Willingness to engage with science-related issues)
- IS 3: Appreciate scientific perspectives and approaches to research (Recognition that scientific knowledge is constantly evolving and changing)

KS: Science Competence
- KS 1: Explaining Phenomena Scientifically (Explaining the potential implications of scientific knowledge)
- KS 2: Explaining Phenomena Scientifically (Identifying, building, and evaluating models)
- KS 3: Explaining Phenomena Scientifically (Remembering and applying appropriate scientific knowledge)
- KS 4: Develop and evaluate designs for scientific investigations and interpret data and evidence critically (Interpret the data presented)
- KS 5: Researching, Evaluating, and Using Scientific Information for Decision Making and Action (Searching for, evaluating, and communicating the relative merits of various sources of information)

Based on Table 8, students from each group generally demonstrated a scientific literacy profile, as seen from their achievement of competencies and aspects of scientific literacy. The differences in students' ability levels in chemistry, as categorized into high, medium, and low, do not fully align with their scientific literacy abilities. This is evident from the diversity of achievements in students' scientific literacy profiles. In this study, students from the medium group demonstrated higher achievement of competencies and aspects of scientific literacy compared to the other groups.

The diversity of students' scientific literacy profiles, as seen in Table 8, is normal. This is due to various factors that influence students' scientific literacy abilities. According to Hayat & Yusuf (in Ardianto, 2016), the learning environment and atmosphere at school influence variations in students' scientific literacy abilities. In addition, other factors such as school facilities and infrastructure, human resources, and school organization and management also significantly influence students' literacy achievements. Firman (Ardianto & Rubini, 2016) also revealed that low scientific literacy achievement is closely related to the gap between applied science learning in schools and the PISA requirements.

Table 8 also shows that science competencies paired with different aspects of science literacy demonstrate differences in the level of achievement of students' science literacy profiles. Differences in students' science literacy achievement within the same science competency indicate that students' science literacy abilities have not developed continuously. This is because this is the first time students have used an ESD-oriented e-module and science literacy, requiring continuous practice to build a strong science literacy profile.

CONCLUSION

The design of the ESD-oriented e-module development on the topic of processing palm oil waste into alternative energy sources was carried out by paying attention to scientific literacy aspects and referring to ESD aspects. The developed e-module meets the characteristics of an e-module and is systematically structured by paying attention to the e-module components, material presentation, and linguistic and graphic aspects. The validation results of the developed e-module indicate that the e-module meets the predetermined criteria, with several suggestions for improvement from the validator. Based on the results of the analysis of answers to the practice questions, it can be concluded that most students have been able to achieve the aspects of scientific literacy and competency required in each practice question. This indicates that the developed e-module has the potential to train students' scientific literacy. However, the developed e-module still needs improvement, both in terms of question construction and strengthening of supporting materials, in order to improve students' understanding of the scientific literacy aspects measured in each question.

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REFERENCE

Alfiani, D. L. N., Rofita, H. D., Efendi, I., & Fatmawati. (2024). Dampak Pembuangan Limbah Pabrik Industri Kelapa Sawit Terhadap Keberlangsungan Hidup Masyarakat Di Kabupaten Indragiri Hulu. *Scientica: Jurnal Ilmiah Sain Dan Teknologi*, *3*(1), 773–780.

Ardianto, D. D., & Rubini, B. (2016). Comparison Of Students' Scientific Literacy In Integrated Science Learning Through Model of Guided Discovery and Problem-Based Learning. *Jurnal Pendidikan IPA Indonesia*, *5*(1), 31–37.

Aribowo, L. A., Kholil, P. A., & Wulandari, T. D. (2025). *Development of Science E-Module Based on Case Method to Improve Students' Problem-Solving Skills*.

Delita, F., Berutu, N., & Nofrion, N. (2022). Online Learning: The Effects Of Using E-Modules On Self-Efficacy, Motivation And Learning Outcomes. *Turkish Online Journal of Distance Education*, *23*(4), 93–107. https://doi.org/10.17718/tojde.1182760

Donkoh, S. (2023). Application of Triangulation in Qualitative Research. *Journal of Applied Biotechnology & Bioengineering*, *10*(1), 6–9.

Ekantini, A., & Wilujeng, I. (2018). The Development of Science Student Worksheet Based on Education for Environmental Sustainable Development to Enhance Scientific Literacy. *Universal Journal of Educational Research*, *6*(6), 1339–1347.

Fitria, Y., & Indra, W. (2020). *Pengembangan Model Pembelajaran PBL Berbasis Digital untuk Meningkatkan Karakter Peduli Lingkungan dan Literasi Sains*. Deepublish.

Fuadi, H., Robbia, A. Z., Jamaluddin, J., & Jufri, A. W. (2020). Analisis Faktor Penyebab Rendahnya Kemampuan Literasi Sains Peserta Didik. *Jurnal Ilmiah Profesi Pendidikan*, *5*(2), 108–116.

Kemendikbud. (2017). *Panduan Praktis Penyusunan E-Modul*. Kementerian Pendidikan dan Kebudayaan.

Kemendikbud Ristek. (2022). *Pedoman Penerapan Kurikulum Dalam Rangka Pemulihan Pembelajaran*. Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi.

OECD. (2023). *PISA 2025 Science Framework*. PISA-OECD Publishing.

Pitoyo, J., Suharto, T. E., & Jamilatun, S. (2022). Bio-oil from Oil Palm Shell Pyrolysis as Renewable Energy: A Review. *CHEMICA: Jurnal Teknik Kimia*, *9*(2), 67.

Pradini, N. L., Wijaya, B. R., & Jannah, A. N. (2022). Analisis Literasi Sains Dalam Upaya Implementasi Pendidikan Abad 21. *Eductum: Jurnal Literasi Pendidikan*, *1*(1), 12–20.

Richey, R. C., & Klein, J. D. (2007). *Design and Development Research: Methods, Strategies, and Issues*. Lawrence Erlbaum Associates Publishers.

Rohmaya, N. (2022). Peningkatan Literasi Sains Siswa Melalui Pembelajaran IPA Berbasis Socioscientific Issues (SSI). *Jurnal Pendidikan MIPA*, *12*(2), 107–117.

Romadhon, M. S., Dianita, E., & Susilawati, S. (2024). Studi Komparatif: Hakikat Bahan Ajar Modul dan LKPD pada Mata Pelajaran IPS dan PPKN di Sekolah Dasar. *Jurnal Ilmiah Madrasah*, *1*(2).

Sholeha, M. (2026). Needs Analysis of the Development of Self-Directed Learning E-Module for the Scientific Writing Course. *Educational Journal of Learning Technology*, *3*(2), 167–181. https://doi.org/10.58230/edutech.v3i2.83

Silaban, R., Elvia, R., & Solikhin, F. (2022). Pengembangan E-Modul Kimia Berorientasi Literasi Sains Pada Materi Kesetimbangan Kimia Di SMA Negeri 3 Bengkulu Tengah. *Jurnal Pendidikan Dan Ilmu Kimia*, *6*(2).

Tartiyoso, S. (2025). Development of STEM-Based E-Module to Enhance Science Literacy and Science Process Skills in Chemistry Learning. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 1124–1132. https://doi.org/10.29303/jppipa.v11i4.10844

Tristananda, P. W. (2018). Membumikan Education for Sustainable Development (ESD) di Indonesia dalam Menghadapi Isu-Isu Global. *Purwadita: Jurnal Agama Dan Budaya*, *2*(2), 42–49.